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CANTALOUP BREEDING CORRELATIONS AMONG FRUIT CHARACTERS UNDER MASS SELECTION
BOHN, G.W., ANDRUS, C.F. 1 OF 1

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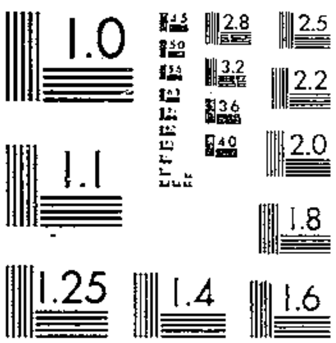

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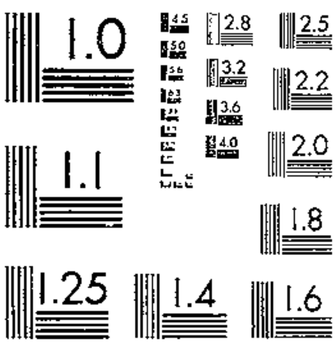

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CONTENTS

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CANTALOUP BREEDING:

Correlations Among Fruit Characters Under Mass Selection

By G. W. BOHN, *geneticist*, and C. F. ANDRUS, *horticulturist*, *Crops Research Division, Agricultural Research Service*

INTRODUCTION

The objective of most practical breeding programs in seed-propagated annual crops, excluding F_1 hybrids, is a variety that is true breeding (uniform) by natural reproduction methods and has a high level of excellence in each character. Insofar as the characters are genetically controlled, such improvement can be accomplished by increases in the frequencies of genes that affect the several characters and by changes in linkages among these genes.

This bulletin is the second of a series of publications initiated in 1960 to discuss new breeding, testing, and selection methods for cantaloups. Such methods will (1) yield greater improvement per unit of invested effort and time; (2) improve several economic characters simultaneously; and (3) increase stability in muskmelons and other partly crossbred crops. We studied simple correlations between 16 fruit characters and partial correlations between 10 characters in 18 related muskmelon populations. Andrus and Bohn (*1*)[1] concluded that eight generations of mass selection by index increased the frequencies of favorable genes for most of the index-component fruit characters in cantaloup, *Cucumis melo* L. The effects of selection on correlations among the index-component characters are discussed in this bulletin.

REVIEW OF LITERATURE

Chace, Church, and Denny (*2*) reported that ripeness and quality in cantaloup cv. Pollock No. 25 were only partly correlated with rind color, color (hue) of stem base, color of ground spot, and "water line" on netting. None of those characters served satisfactorily as a guide to pre-slip harvest. Rosa (*16*) noted that in muskmelon fruits low density was associated with oblate shape and high density, with oblong shape. Scott (*17*) confirmed Rosa's observations, but he believed that correlation values between shape and density were too weak to justify the use of one character as an index of the other. He found weight to be correlated with density or with shape in occasional breeding lines;

[1] Italic numbers in parentheses refer to Literature Cited, p. 20.

but he concluded, from the low *r* values, that any desired weight, shape, and density of fruit could be combined in a single breeding line.

In 1967, Wall (*21*) correlated inheritance of fruit shape with sex type in both *Cucumis melo* and *C. sativus* L. He concluded that a major gene, *O*, for oval fruit, was linked in coupling phase with a major gene, *A*, for monoecious sex expression in *C. melo*.

Hoffman (*8*) reported correlation coefficients between weight, density, cavity factor, density of sliced fruit, and refractive index to vary within 15 muskmelon cultivars. He found highly significant correlations, within most varieties, among several fruit density components and fruit weight, but only rarely did he find significant correlations between these characters and soluble solids. Wagner, Hoffman, and Brown (*20*) reported high correlations between refractive index and vitamin C in each of 16 cultivars.

Currence and Larson (*3, 4*) reported that flavor, determined by a panel of tasters, was highly correlated with refractive index of the juice and with fruit weight. They reported a multiple correlation coefficient of flavor with weight and soluble solids among muskmelons to be 0.909 ± 0.342. They noted great variability in accuracy of tasters, and they remarked that a single refractometer reading was as accurate as the mean of six to eight taste observations. The multiple regression coefficient was equal to 12 such observations.

Jacob and White-Stevens (*9*) reported high correlations of flavor with total sugars, dispersed solids, and their components in fruits from plants treated with various fertilizers. All these characters responded similarly to environmental effects induced by magnesium and potassium applications. Takagi (*19*) found that netting, rind hardness, flesh thickness, and sugar content were all affected by artificial leaf pruning. Rahn and Heuberger (*15*) found a high correlation between soluble solids in the fruit flesh and degree of downy mildew control with fungicides. Nylund (*13*) correlated fruit earliness, weight, soluble solids content, and degree of netting with defoliation by pruning and with varying nitrogen supply. From partial correlations, he concluded: "Early-maturing fruits tended to be heavier than late fruits; and these heavier fruits tended to be more deeply netted and to have higher soluble solids than did light fruits." Nylund observed that environment manipulations "that affected fruit weight also tended to affect time of maturity, netting, and percent soluble solids."

Ogle and Christopher (*14*) reported good correlation between firmness determined by Chatillon needle-pressure tester and keeping quality in storage with different harvest and postharvest environmental treatments (stage of maturity at harvest, storage temperature, and storage duration). They reported, also, an apparent genetic correlation with variety.

Davis, Baker, and Kasmire (*5*) attributed within-location heterogeneity in several uncorrelated characters to genetic heterogeneity in cv. PMR 45. They attributed significant between-location correlations to environmental rather than genetic causes. Factor analyses indicated that environmental factors that affected net toughness, net height, and groundspot size were different from those that affected other characters; other characters were closely interrelated. The high environmental correlations they observed agree with results obtained by Jacob and White-Stevens (*9*) and others. For example, Lingle and Wight (*10*) observed that nitrogen deficiency reduced fruit size, net distribution, and soluble solids in the cv. PMR 45.

Subsequently, Davis and coworkers (*7*) reported that fruit diameter and flesh thickness were correlated with seed number per melon in some fields but not in others. They were correlated, also, across fields. However, flesh proportion (flesh depth index in Andrus and Bohn's (*1*) terminology) was not correlated with seed number. Davis, Davis, and Meinert (*6*) reported both genetic and environmental correlations among leaf shape, flesh proportion, and fruit shape in the cv. PMR 45 and a verticillium-resistant line selected from it.

Andrus and Bohn (*1*) used regression of character means on generations together with direct comparisons of means, in successive mass-selected generations to demonstrate genetic improvement by index selection. The results from all sources confirmed their observation that muskmelon cultivars, especially netted ones, are extremely variable (unstable) in several fruit characters. Most reports indicate that some muskmelon fruit characters respond similarly to environment changes and exhibit correlated environmental responses but that other characters respond independently to major and minor environment changes and appear uncorrelated both within and between plantings.

In brief, the literature indicates that high environmental correlations occur among certain fruit characters in cantaloups but are lacking in others. Scant evidence on putative genetic correlations suggests that they can be improved by breeding.

MATERIALS AND METHODS

A detailed account of pedigree, selection method, and testing procedure was given in an earlier paper (*1*). It is sufficient to note here that the populations included nine successive mass generations and nine derived inbred populations—three from early mass-increased generations, three from M4, and three from M7. We grew the 18 populations in three 100-hill replications at each of two locations: Charleston, S.C., during the spring of 1964 and Brawley, Calif., during the fall of 1964. We harvested a single fruit from each hill to obtain random samples of each test population. The Brawley planting, in a low-stress environment that supported healthy plant growth, yielded nearly complete 300-fruit samples for each test population. Data from it received primary consideration and analysis. The Charleston planting, in a high-stress environment that produced many diseased plants, yielded smaller samples. Data from it supported the findings at Brawley.

Intergeneration correlation coefficients among the index-component characters (and between them and generations) were calculated for the nine mass-selected populations grown at each location. Correlation coefficients were calculated, also, for the character pairs within each population grown in the low-stress environment at Brawley. Partial correlations were calculated for some character combinations within certain mass-selected and inbred populations.

The breeding objective was to obtain fruits with values greater than those of the M1 base population for most characters. Such characters and those with desired means intermediate in the whole range of character expression were described as "positive." In contrast, selection pressure was exerted toward fruits with smaller stem scars, smaller blossom scars, and smaller seed cavities. We termed those characters "negative." The plus and minus signs obtained from calculations were adjusted, where necessary, in all tables to indicate favorable correlations and unfavorable ones.[2] Thus, the tendency of large fruits (positive) to have large seed cavities (negative) was indicated by $r=-0.58$ in table 1; but the tendency of fruits with small stem scars (negative) to have small cavities (negative) was indicated by $r=0.25$.

RESULTS AND DISCUSSION

Correlation With Generation

Regression on generation number of measured characters, calculated from original data, was given in an earlier paper (*1*, fig. 8). Comparisons therein are confounded by differences among means and variances. Regression on generation number of 16 characters, calculated from standard variables (*18*), is shown here in figure 1. The character relations are discussed herein in terms of the correlation coefficient r (covariance of standard variables) free from differences in means and variances.

Coefficients of correlation of population means for fruit characters with generation number in the nine mass-selected generations indicated that blossom scar size, net thread size, crack resistance, relative flesh depth, stem scar size, number of acceptable characters, and total score were very responsive (1-percent level of significance) to mass selection by index (fig. 1 and table 1, line 1). Weight, flesh color, and external appearance were responsive (5-percent level of significance). Fruit size, shape, flesh firmness, freedom from bare sutures (vein tracts), and net thread cover were questionably responsive. Soluble solids and cavity dryness were not responsive. The results indicate that certain characters, especially soluble solids and cavity dryness in this experiment, require greater emphasis in index selection.

Correlation Between Generation Means

Most of the coefficients of correlation between generation means among the selection-responsive fruit characters were similar to their coefficients with generation number (table 1, above the diagonal). This suggests that improved relations among the characters paralleled their separate improvement from generation to generation.

Certain characters failed to follow that trend. Relative flesh depth, weight, and size means yielded exceptionally high coefficients with one another and exceptionally low coefficients with several other characters. The correlations of flesh depth with size and weight are not

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[2] Unfavorable correlations are indicated by minus signs (−) in the tables and favorable correlations by plus signs (+) in table 3 and by absence of any sign in other tables.

TABLE 1.—*Phenotypic correlation coefficients of population means for fruit characters in mass-selected populations 1 to 9, above the diagonal; and inbred populations 10 to 18, below the diagonal, Brawley, Calif., 1964* [1]

Character	Generation	Blossom scar size	Net thread size [2]	Crack resistance [2]	Flesh depth	Stem scar size	Weight	Flesh color [2]	External appearance [2]	Size (crate)	Shape [2]	Flesh firmness [2]	Sutureless [2]	Net thread cover	Soluble solids	Cavity dryness [2]	Acceptable characters	Total score
	Number	*Mm.*			*Pct. cav.*	*Mm.*	*G.*							*Pct.*	*Pct.*		*Number*	
Generations	----	0.98	0.86	0.85	0.84	0.81	0.78	0.76	0.75	0.66	0.59	0.59	0.55	0.50	0.18	−0.13	0.90	0.85
Blossom scar size	0.10	----	.92	.93	.77	.82	.75	.87	.81	.66	.72	.70	.66	.59	.31	−.09	.95	.92
Net thread size	.70	−.46	----	.94	.69	.60	.70	.94	.95	.72	.90	.70	.78	.80	.47	.08	.98	.98
Crack resistance	.78	.22	.44	----	.58	.75	.61	.97	.85	.58	.86	.79	.81	.73	.50	.09	.96	.95
Flesh depth	.63	.23	.24	.89	----	.51	.95	.47	.60	.83	.38	.18	.25	.28	−.28	−.37	.71	.68
Stem scar size	.26	.68	−.24	.53	.57	----	.48	.66	.50	.22	.37	.69	.54	.37	.29	−.12	.70	.65
Weight	----	----	----	----	----	----	----	.77	.67	.89	.42	.29	.39	.39	−.23	−.22	.73	.73
Flesh color	.63	−.42	.93	.34	.14	−.33	----	----	.90	.51	.92	.83	.89	.84	.65	.21	.95	.95
External appearance	.72	.30	.90	.32	.04	−.11	----	.84	----	.67	.87	.74	.89	.92	.54	.26	.93	.97
Size (crate)	.56	.06	.24	.60	.29	.21	----	.22	.38	----	.56	.23	.36	.41	−.17	−.12	.67	.70
Shape	.40	.55	.07	.14	.02	.26	----	.29	.28	.10	----	.71	.80	.82	.65	.16	.84	.88
Flesh firmness	.08	−.55	.53	.25	.10	−.37	----	.65	.30	.19	.19	----	.89	.75	.76	.36	.74	.75
Sutureless	.47	−.14	.70	.23	−.07	.12	----	.59	.86	.32	.14	.26	----	.95	.75	.49	.80	.85
Net thread cover	.43	−.38	.71	.09	−.23	−.10	----	.62	.91	.37	.12	.24	.92	----	.73	.50	.78	.84
Soluble solids	.64	−.17	.81	.61	.29	.13	----	.67	.82	.48	.08	.43	.81	.75	----	.55	.44	.47
Cavity dryness	.48	−.08	.55	.58	.19	.21	----	.45	.64	.73	.00	.44	.75	.68	.89	----	.10	.12
Acceptable characters	.76	.25	.64	.79	.54	.48	----	.58	.66	.52	.35	.33	.72	.50	.83	.78	----	.99
Total score	.82	−.02	.81	.71	.44	.29	----	.74	.84	.50	.32	.38	.81	.68	.90	.78	.96	----

[1] Significant coefficients with 7 d.f.: 0.67 at 5 percent, 0.80 at 1 percent.

[2] This character was scored on an arbitrary 1 to 5 integer scale.

necessarily high because flesh depth is here expressed as a percentage of cavity diameter; hence, equivalent changes of real flesh depth and cavity diameter would yield a zero coefficient. The high coefficients suggest that selection for each of the three characters may have enhanced the other two.

The lower correlations of those three characters with others suggest that gains in flesh depth occurred mostly in larger, heavier fruits without comparable improvement in other characters. This trend could be reduced by adjusting relative weights of the index components. For example, the selection values of weight and size could be reduced in the index. This would place greater selection pressure on the remaining characters. Similarly, extra value could be placed on thick-fleshed fruits with firm flesh, dry cavities, and high soluble solids to increase selection pressure for those associations.

The failure of soluble solids and cavity dryness to respond to index selection was indicated by the study of population means (*1*) and by their lack of correlation with generations reported herein. This was supported further by generally low coefficients for correlation with means for other characters (table 1, lines 15 and 16). The data indicated that adjustment of testing procedure, sampling procedure, or index values will be required to make the index effective for soluble solids and cavity dryness.

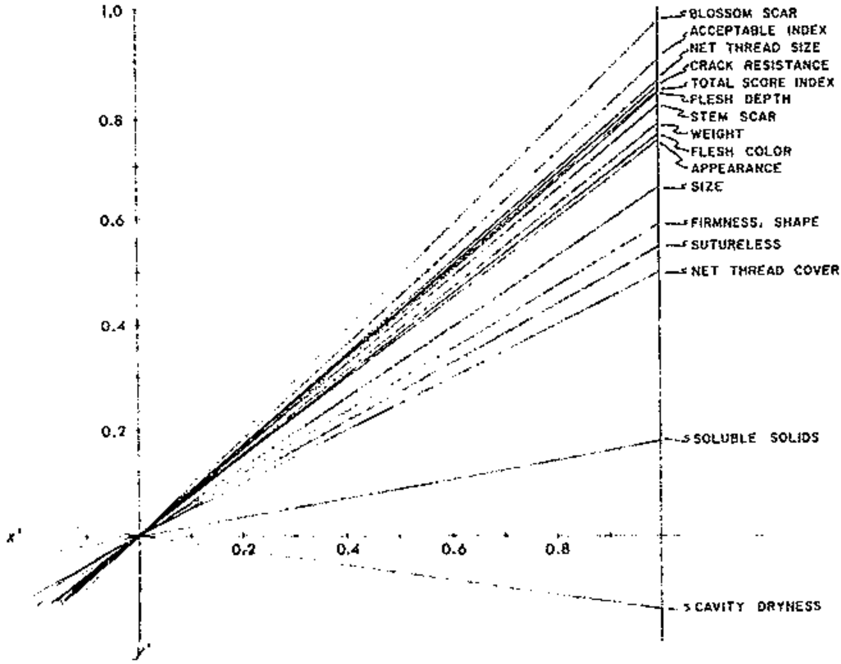

FIGURE 1.—Regression of fruit characters on generations in muskmelon C434–C–3–M1 to C434–C–3–M9 grown at Brawley, Calif., during the fall of 1964. Data converted to standard variables x′ (generations) and $y'_{1\text{--}x}$ (characters) with zero means and unit variance. Cov-b′-r. From Steel and Torrie (*18, p. 184*).

Characters that yielded nearly significant correlations with generations did yield significant coefficients in correlations with several other characters, including the selection indexes (table 1, above the diagonal). The results give credence to the view that those characters did respond to mass selection by index despite nonsignificant correlations with generations.

The correlation coefficients among generation means of 10 characters in populations grown at Charleston confirmed the findings at Brawley with few exceptions. Stem scar size, significantly correlated with generations and blossom scar size at Brawley (r=0.81**[3] and 0.82**), was not so correlated at Charleston (r=0.056 and 0.147). Blossom scar size was significantly improved at both locations. The data suggest a high interaction of genes for stem scar size with environmental factors at the two locations. The predominance of similar correlation coefficients at the two locations suggests that most of the genetic controls in muskmelon may be fairly stable.

Correlation coefficients for mean vitamin C content of populations 1 to 9 grown at Charleston indicated that it was not affected by selection. It was highly correlated with stem scar size (r=0.86) and soluble solids (r=0.71) but not with six other characters (the two indexes, flesh depth, blossom scar size, fruit weight, and net thread cover). No significant correlations were found among eight index-component character means in the inbred populations grown at Charleston.

The coefficients of correlation among population means in inbred populations 10 to 18 grown at Brawley (table 1, below diagonal) often differed from those in mass-selected populations 1 to 9 (table 1, above diagonal); they differed extremely in some character associations. For example, blossom scar size, which had high positive correlations with several characters in mass-selected populations, had a single significant correlation, that with stem scar, in inbreds. Extreme differences occurred between mass and inbred populations in the correlations of blossom scar size with net thread size (+0.92 and −0.46), flesh color (+0.87 and −0.42), and flesh firmness (+0.70 and −0.55). Such differences in correlations of population means in the small number of populations sampled support the data on coefficients of variability and indicate great genetic variability. The large shifts in correlation coefficients indicate that character associations are not fixed in the breeding lines, so that any combination of character expression can be derived from them by appropriate breeding and selection procedures. The greater prevalence of high positive correlations and the absence of high negative correlations in the mass-selected populations (in comparison with the inbred ones) support the view that mass selection is more effective than strict inbreeding with selection to improve several complex characters in early-generation populations.

A few characters yielded similar correlation coefficients in both mass-selected and inbred populations. For example, net thread size, external appearance, and flesh color were highly correlated with one another in both sorts of populations. Such agreement suggests (1) pleiotropy or very close linkage of genes affecting those characters

[3] Significant at the 1-percent level.

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or (2) comparatively large environmental effects associated with vigor. If pleiotropy or linkage applies, then such favorable correlations should aid rather than hinder selection; but if large environmental effects occur, they would greatly reduce effectiveness of selection.

The absence of negative correlations and the variability in each character indicated that the plant material (Muskmelon C434–C–3) is suitable for selection and that it is capable of yielding, from appropriate breeding and selection procedures, a variety with improved quality in all fruit characters.

The correlation between population mean values for fruit characters indicated overall improvement by mass selection in all character associations except those of soluble solids and cavity dryness. Lower and more variable coefficients for correlations among the same char-

TABLE 2.—*Phenotypic correlation coefficients between fruit characters and within mass-selected population C434–C–*

Character	Weight	Diameter	Size (crate)	Stem scar size [2]	Cavity size [2]	Cavity dryness [3]	Appearance [3]	Net thread cover
	G.	*Mm.*		*Mm.*	*Mm.*			*Pct.*
Weight	------	0.93	0.87	−0.62	−0.56	0.36	0.34	0.30
Diameter	0.95	------	.85	−.61	−.70	.45	.40	.38
Size (crate)	.87	.87	------	−.62	−.58	.35	.39	.33
Stem scar size [2]	−.49	−.51	−.50	------	.50	−.19	−.30	−.22
Cavity size [2]	−.51	−.64	−.48	.25	------	−.47	−.28	−.40
Cavity dryness	.33	.40	.29	.00	−.41	------	.26	.36
Appearance	.52	.51	.47	−.14	−.22	.32	------	.59
Net thread cover	.42	.42	.36	−.09	−.28	.34	.79	------
Net thread size	.40	.42	.34	−.19	−.23	.23	.67	.70
Sutureless	.13	.16	.05	.17	−.19	.16	.47	.59
Flesh depth	.45	.37	.42	−.28	.47	−.04	.32	.14
Flesh color	.15	.18	.17	−.14	−.03	.23	.35	.27
Soluble solids	.14	.21	.16	−.05	−.35	.44	.36	.35
Flesh firmness	.26	.27	.27	.05	−.12	.36	.37	.36
Crack resistance	−.25	−.25	−.21	.48	.17	−.12	−.03	−.02
Blossom scar size [2]	−.08	−.16	−.03	.19	.23	−.06	−.09	−.07
Shape	−.24	−.02	.00	−.01	.15	−.06	.26	.14
Favorable number	11	11	10	4	5	10	12	12
Unfavorable number	4	4	3	7	9	1	2	1

[1] Significant coefficients for M1 (289 fruits), $r = 0.117$ at 5 percent, 0.153 at 1 percent; for M9 (244 fruits), 0.128 at 5 percent, 0.167 at 1 percent.

[2] Small measures were desired in this "negative" character.

[3] This character was scored on an arbitrary 1 to 5 integer scale.

acters in inbred population means indicated, from the small number of populations, that strict inbreeding is a less effective breeding procedure than mass selection for early-generation hybrids.

Correlation Within Populations

The correlation coefficients in the base population C434–C–3–M1 indicated very close associations between obviously related characters such as that of fruit weight with diameter ($r=+0.93$). Most other correlations were considerably lower, but a surprisingly large number (75 of 136 different coefficients, each counted twice in table totals =55 percent) were significant (table 2, above diagonal). Forty percent of the correlations were significantly favorable and 15 percent were significantly unfavorable; the others were nonsignificant.

within muskmelon base population C434–C–3–M1, above diagonal; 3–M9, below diagonal, Brawley, Calif., 1964 [1]

Net thread size [3]	Sutureless [3]	Flesh depth	Flesh color [3]	Soluble solids	Flesh firmness [3]	Crack resistance [3]	Blossom scar size [2]	Shape [3]	Favorable	Unfavorable
		Pct. cav.		*Pct.*			*Mm.*		*Number*	*Number*
0.10	−0.05	0.31	0.08	0.08	0.06	0.04	0.12	0.04	7	2
.20	.02	.23	.17	.14	.05	.03	.04	−.06	9	2
.20	−.02	.22	.11	.16	.03	.09	.09	.07	8	2
−.14	.02	−.03	−.06	−.12	−.08	.25	−.07	−.02	2	8
−.24	−.17	.53	−.05	−.23	−.05	−.03	.06	.08	2	9
.15	.12	−.11	.01	.29	.13	.07	.07	−.09	9	2
.51	.34	.06	.22	.23	.12	.16	.07	.07	11	2
.53	.40	.44	.09	.25	.10	.14	−.09	−.12	10	3
	.30	−.11	.25	.31	.06	.18	−.11	−.07	9	2
.39		−.24	.11	.08	.15	.14	−.06	.04	6	2
.19	−.03		.04	−.13	−.02	−.02	.14	.04	6	2
.37	.09	.17		.30	.16	.20	−.09	.07	6	0
.44	.19	−.18	.45		.22	.06	−.19	.03	8	4
.27	.21	.15	.24	.45		.04	.02	.11	5	0
.00	.05	−.08	−.07	−.06	.04		−.08	.05	6	0
−.15	−.04	.09	−.16	−.23	.06	.15		.15	3	1
.19	.11	.17	.04	.13	.01	.10	−.01		2	1
									[4] 108	[5] 42
12	9	10	10	11	11	3	3	6	[6] 150	----
3	1	2	2	3	0	3	4	1	----	[7] 50

[4] 40 percent.
[5] 12 percent.
[6] 55 percent.
[7] 18 percent.

The extremely large correlation coefficients, approaching unity, between weight, diameter, and estimated size suggest that they are duplicate characters. They furnish three estimates of fruit mass. In agreement with this interpretation, they exhibited similar correlations with other variables (table 2, above diagonal) and provided a reference point from which the remaining data may be evaluated.

Many of the large, favorable correlations occurred between obviously dependent and their independent, control characters such as those of external appearance with net thread size and net thread cover ($r=+0.51$ and $+0.59$, respectively). Other favorable correlations occurred between characters dependent upon a third, often unmeasured, character. For example, muskmelon fruits located in favorable positions on a plant, or on more vigorous plants, often have both better external appearance and better internal characters. The comparatively low but still highly significant correlations of external appearance with flesh color and soluble solids ($+0.22$ and $+0.23$, respectively) seem most likely to be of this type. Such environment-induced correlations hinder progress in selection, because they favor high index scores of favorably located fruits.

The large unfavorable correlations could be attributed to interdependence of "negative" characters (smaller actual values desired) with "positive" characters (larger actual values desired). For example, stem scar size and cavity size (both negative) were highly and unfavorably correlated with fruit weight and diameter (both positive), $r=-0.62$ and -0.56; -0.61 and -0.70, respectively. The "negative" characters stem scar size and cavity size accounted for 34 of the 42 listed (17 of 21 actual) unfavorable correlations. Curiously, the third "negative" character, blossom scar size, was unfavorably correlated with only one other character, soluble solids ($r=-0.19$). Such correlations hindered the production of fruits with favorable combinations, and several in concert tended to hinder the selection by index of large fruits with small stem scars and small cavities.

C434–C–3–M9 was an F_{13} population derived from the C434–C–3–M1 (F_5) generation by eight generations of mass selection. Plant characters including disease resistance were ignored in selection; all selection pressure was exerted for desirable fruit characters. Fifty percent selection pressure was exerted against "slicker," sunburned, split, runt, and badly malformed fruits in the field. Selection pressure at 20 percent was exerted on the retained sample of 300 fruits by fruit character index. Many (68 percent) of the correlations between fruit characters in M9 (table 2, below diagonal) were improved over those in M1 (table 2, above diagonal), several of them (29 percent) significantly so (table 3). Most of the correlations were so improved that 55 percent achieved favorable significance in M9 compared with 40 percent in M1.

All correlation coefficients of appearance, except those with blossom scar size and crack resistance, were improved by index selection; eight of them were significantly improved. Most of the other characters responded to lesser degree but in a similar fashion. The prevalence of positive signs in table 3, denoting improved correlation relationships, carries weight in addition to that of the significant changes. They furnish potent evidence in support of the conclusions derived from the study of population means: Most of the component characters were simultaneously improved by index selection, and the improvement was associated with genetic changes resulting in improved complexes of genes controlling the several characters. Such genetic changes during mass selection would greatly improve the chances of success in obtaining plants superior in all fruit characters.

Blossom scar size and crack resistance failed to follow the general trend and performed in an obtuse manner in their relationships with other characters. Ten of the 16 correlations of blossom scar size were changed unfavorably but only two of the changes were significantly large (table 3). Three of the six favorable changes, those with stem scar size, crack resistance, and cavity size, were significantly large. Hence, the favorable and unfavorable shifts in correlations of blossom scar size were nearly balanced. The failure to obtain prevalence of favorable changes could have resulted from inclusion of blossom scar size in the index in only a part of the selected generations.

Unfavorable changes occurred in 10 of the 16 correlations of crack resistance and seven of them were large enough to be significant (table 3, column 15 and line 15). Three of the four favorable changes were significantly large. The prevalence of unfavorable changes may have resulted from the practice of discarding cull fruits in the fields during selection. Elimination of severely cracked fruits without regard to their other characters could have caused the observed unfavorable shifts in early generations; but these should be reversed with continued selection pressure in populations relatively free from such defects.

Eleven of the 16 correlations of cavity size were improved but only three of them significantly so. The strong negative correlations with size, dryness, and soluble solids have been noticed in other cantaloup breeding lines; they may be nongenetic. If that is true, they may limit the degree of expression that can be achieved simultaneously.

This is not a serious problem because extreme expression of most characters is not desired in a commercial cantaloup. For example, consumers prefer cantaloup sizes 36 and 27, which weight 2.5 to 3.5 pounds. On western markets size 18 and larger cantaloups, weighing 5 or more pounds, are sold as stock feed rather than for human consumption. Similarly, the crop is grown from seed so that the acceptable limit of small cavity size is influenced by the requirement for seed space. Accordingly, a cavity diameter equal to about one-fourth of the fruit diameter is preferred over one that occupies either more or less space.

The correlation data from C434–C–3–M1 and C434–C–3–M9 support and extend the data reported earlier. Data on means, coefficients of variability, and correlation with generations demonstrated that the natural breeding structure of cantaloup populations makes them responsive to selection pressure exerted on several characters simultaneously. The correlation data within populations indicate that the improvement was associated generally with improved correlation relations, and they strongly suggest that favorable crossovers that plant breeders seek have indeed occurred.

Correlations for each character with other characters and indexes within each of the 18 muskmelon populations were compared for uniformity of behavior and response to selection. The within-population correlation coefficients of any one character with the remaining char-

TABLE 3.—*Favorable (+) and unfavorable (−) changes in z values*[1] *and C434–C–3–M9 harvested at*

Character	Diameter	Size (crate)	Stem scar size	Cavity size	Cavity dryness[3]	Appearance[3]	Net thread cover	Net thread size[3]
	Mm.		*Mm.*	*Mm.*			*Pct.*	
Weight	+0.11	−0.04	*+0.19	+0.08	−0.02	*+0.22	+0.14	*+0.32
Diameter	------	+.08	+.15	+.10	−.06	+.14	+.05	*+.25
Size (crate)	------	------	*+.17	+.14	−.06	+.09	+.03	+.15
Stem scar size	------	------	------	*−.29	*+.19	*+.17	+.13	−.05
Cavity size	------	------	------	------	+.07	+.07	*+.23	+.01
Cavity dryness	------	------	------	------	------	+.06	−.03	+.09
Appearance	------	------	------	------	------	------	*+.39	*+.25
Net thread cover	------	------	------	------	------	------	------	*+.27
Net thread size	------	------	------	------	------	------	------	------
Sutureless	------	------	------	------	------	------	------	------
Flesh depth	------	------	------	------	------	------	------	------
Flesh color	------	------	------	------	------	------	------	------
Soluble solids	------	------	------	------	------	------	------	------
Flesh firmness	------	------	------	------	------	------	------	------
Crack resistance	------	------	------	------	------	------	------	------
Blossom scar size	------	------	------	------	------	------	------	------
Shape	------	------	------	------	------	------	------	------
Number	------	------	------	------	------	------	------	------
Percent[4]	------	------	------	------	------	------	------	------

[1] *z* values calculated by methods indicated in Steel and Torrie (*18*).
[2] *, significant change, 0.174.

acters were surprisingly uniform in the 18 muskmelon populations. The uniformity suggested that environmental variation and the resulting environmental correlations were far greater in magnitude than genetic variation and correlation in the nine mass-selected populations and their nine derived inbreds. It follows that significant improvement through mass selection by index depends upon separation of genetic effects from the overriding environmental effects on variation.

Hopefully, such studies will eventually be made to speed progress in vegetable breeding with its multiple-character index requirement. At present it seems desirable to explore alternatives that can be more readily tested and discarded or put to immediate use. Partial correlations were studied to determine their potential merits.

for correlations among fruit characters of muskmelon C434–C–3–M1 Brawley, Calif., during fall 1964 [2]

Sutureless [3]	Flesh depth	Flesh color [3]	Soluble solids	Flesh firmness [3]	Crack resistance [3]	Blossom scar size	Shape [3]	Significant changes +	Significant changes −	Total changes +	Total changes −
	Pct. cav.		*Pct.*			*Mm.*					
*+0.18	*+0.17	+0.07	+0.06	*+0.21	*−0.29	*−0.20	*−0.28	6	3	11	5
+.14	+.14	+.01	+.07	*+.22	*−.28	*−.20	+.04	2	2	13	3
+.07	*+.23	+.06	0	*+.25	*−.30	−.12	−.07	3	1	10	5
+.15	*−.25	−.08	+.07	+.13	*+.26	*+.27	−.01	6	2	11	5
−.02	−.08	+.02	−.14	−.07	*+.20	*+.17	+.07	3	1	11	5
+.04	+.07	*+.23	*+.17	*+.24	*−.19	−.13	+.03	4	1	10	6
*+.17	*+.27	+.14	+.14	*+.27	*−.19	−.16	*+.20	8	1	14	2
*+.26	*−.33	*+.19	+.11	*+.27	−.16	+.02	*+.26	7	1	13	3
+.10	*+.30	+.13	+.15	*+.21	*−.18	−.04	*+.27	7	1	13	3
------	*+.21	−.02	+.11	+.06	−.07	+.02	+.07	4	0	13	3
------	------	+.13	−.05	*+.17	−.06	−.05	+.13	6	2	10	6
------	------	------	*+.18	+.08	*−.27	−.07	−.03	3	1	11	5
------	------	------	------	*+.26	0	−.05	+.10	3	0	11	3
------	------	------	------	------	0	+.04	−.10	9	0	13	2
------	------	------	------	------	------	*+.24	+.05	3	7	4	10
------	------	------	------	------	------	------	−.16	3	2	6	10
------	------	------	------	------	------	------	------	3	1	10	6.
------	------	------	------	------	------	------	------	80	26	184	82
------	------	------	------	------	------	------	------	29	10	68	30

[3] This character was scored on an arbitrary 1 to 5 integer scale.

[4] Obtained by dividing the number of changes by 272 (136 values in table X2).

Partial Correlations

The relation between two fruit characters can be partly freed from effects of environmental covariance and of genetic linkage with other characters by the device of partial correlation. The residual partial correlations should more accurately estimate the fundamental phenotypic association between the two characters. Accordingly, partial correlations were calculated for 10 selected characters in the 18 muskmelon populations. The number of characters was limited to 10 by the capacity of the computer program. The effects of variation in the eight other characters were eliminated in each partial correlation between any two characters.

Most correlations in the base population C434–C–3–M1 were greatly reduced by the partial-correlation technique (table 4, above diagonal, compare with table 2). The resulting partial correlations were mostly small and not significantly different from zero.

Most partial correlations in M9 did not differ significantly from those in M1 (table 4). Significant improvement occurred in six partial correlations: stem scar size with both blossom scar size and sutureless, net thread size with both cavity size and fruit diameter, and thread percentage with both weight and sutureless. One partial correlation, that of stem scar size with cavity size, deteriorated.

A slight excess (62 percent) of the partial correlations in M9 were improved over those in M1, 18 percent of them significantly so (table 4). This may seem to indicate little improvement in correlations among the various characters. However, it is rather impressive if one considers the very low selection differential applied to each character through the multiple-character index; and, further, that the shifts in genetic correlations may very well be greater than the shifts in phenotypic correlation reported here.

Most of the resulting partial correlation coefficients in M9 were significantly favorable or nonsignificant (table 4, below diagonal). The only significant negative correlation was that between cavity size and fruit diameter. That correlation indicates that selection for small cavity alone would reduce fruit diameter; it emphasizes the need to include both characters in the selection index. The extreme favorable correlation of weight with diameter and its significant favorable correlation with cavity size suggest that weight would improve with selection for those characters and need not be included in the index.

The small partial correlation coefficients for other character pairs indicate that continued selection for one character did not interfere with simultaneous selection for another. These are phenotypic correlations; negative genetic correlations could be hidden by opposing environmental correlations.

The extremely high total correlation between weight and diameter in all populations was little changed by removing effects of variation in the other eight characters (e.g., table 5, lines 1 and 2). This supports the conclusion, reached from the study of total correlations, that fruit weight and diameter are largely duplicate characters measuring fruit mass on different scales.

In contrast with the minute effects of other characters on the weight-diameter correlation, removal of effects of other correlations on those of weight with the other eight characters had large effects on the residual partial correlations (table 5, lines 1 and 2). The very high total correlation of stem scar size with weight was greatly reduced by removal of effects of correlation with diameter and other characters. (Similarly, its very high total correlation with diameter was nullified by removal of effects of correlation with weight and other characters.) Extreme effects of the partial-correlation technique included the shift in the association between cavity size and fruit weight. Removal of variation in other variables (characters) shifted that association from $r = -0.56$ to $r_{12 \cdot 3 \cdots 10} = +0.204$. Apparently, the removal of other sources of correlation, especially that with fruit mass indicated by diameter, uncovered a positive correlation between small cavity size

TABLE 4.—*Partial correlations, adjusted for others in the table, among 10 fruit characters in muskmelon base population C434–C–3–M1, above the diagonal; and derived population C434–C–3–M9, below the diagonal, Brawley, Calif., fall 1964*

Character	Blossom scar size	Net thread size [1]	Cavity size	Stem scar size	Weight	Diameter	Sutureless [1]	Net thread cover	Soluble solids	Cavity dryness [1]
	Mm.		*Mm.*	*Mm.*	*G.*	*Mm.*		*Percent*	*Percent*	
Blossom scar size	--------	−0.023	0.067	−0.058	0.106	−0.051	0.011	−0.036	−0.158	0.031
Net thread size	0.013	--------	.003	−.084	−.113	−.098	.109	.408	.223	−.098
Cavity size	.074	.192	--------	.212	.204	−.411	−.141	−.026	−.067	−.188
Stem scar size	.166	−.039	−.024	--------	−.206	−.016	.055	.011	−.050	.144
Weight	.188	−.022	.275	−.074	--------	.854	−.053	−.077	.014	−.042
Diameter	−.081	.149	−.479	−.115	.898	--------	.034	−.138	.035	−.159
Sutureless	.008	.002	−.097	.229	−.149	.111	--------	.301	−.060	.004
Net thread cover	−.001	.519	−.007	−.021	.175	−.177	.501	--------	.027	.173
Soluble solids	−.145	.324	−.204	−.060	−.109	−.024	−.063	.048	--------	.193
Cavity dryness	.106	−.150	−.081	.209	−.069	−.188	−.106	.165	.351	--------

[1] This character was scored on an abitrary 1 to 5 integer scale.

TABLE 5.—*Partial correlations of fruit weight in mass-selected (M) and inbred populations of muskmelon C434–C–3, Brawley, Calif., fall 1964*

Generation Weight with	Diameter	Stem scar size	Cavity size	Cavity dryness [1]	Net thread cover	Net thread size [1]	Suture-less [1]	Soluble solids	Blossom scar size
	Mm.	*Mm.*	*Mm.*		*Percent*			*Percent*	*Mm.*
M1 total correlation	0. 93	−0. 62	−0. 56	0. 36	0. 30	0. 10	−0. 05	0. 08	0. 12
Partial correlation:									
M1	. 854	−. 206	. 204	−. 042	−. 077	−. 113	−. 053	. 014	. 106
M4	. 902	−. 104	. 219	. 042	. 029	−. 162	−. 157	−. 025	. 013
M7	. 906	−. 039	. 165	. 001	−. 064	−. 087	. 191	. 028	. 075
M9	. 898	−. 074	. 275	−. 069	. 175*	−. 022	−. 149	−. 109	. 188
M4	. 902	−. 104	. 219	. 042	. 029	−. 162	−. 157	−. 025	. 013
13=M4 Inbred	. 883	−. 193	. 379	−. 036	. 001	−. 019	−. 052	. 135	. 019
14=M4 Inbred	. 865	−. 257	. 093	−. 052	. 176	−. 003	−. 015	. 059	. 064
15=M4 Inbred	. 920	−. 036	. 155	−. 147	−. 014	−. 076	. 042	−. 005	−. 068
M7	. 906	−. 039	. 165	. 001	−. 064	−. 087	. 191	. 028	. 075
16=M7 Inbred	. 910	−. 024	. 332	−. 073	. 026	−. 041	−. 010	−. 059	. 108
17=M7 Inbred	. 911	−. 108	. 278	. 017	. 016	−. 083	−. 038	. 061	. 109
18=M7 Inbred	. 886	−. 192	. 221	. 054	−. 012	−. 038	. 130	. 077	. 048

[1] This character was scored on an arbitrary 1 to 5 integer scale.
*Significant at 5-percent level.

and the residual weight components length and density. This could well be expected because small cavities were usually filled with placenta tissues and seeds, while large ones often included an airspace.

The reduction, by means of partial correlation, of correlations among most characters associated with fruit weight suggest that those relations resulted largely from environment-induced covariation. In other words, favorable position of a plant in the field and favorable position of a fruit on the plant favored vigorous fruit growth and resulted in larger, heavier fruits with larger stem scars, larger and drier cavities, and more abundant and larger net threads. Correlations of soluble solids appeared to be only slightly affected by such factors; those of sutureless and blossom scar size, not at all.

Differences among the base population and various derived populations in partial correlation between two characters may indicate changes in genetic linkage. The required assumption is that environmental correlations within a single experiment are similar in the different populations. Matzinger, Mann, and Cockerham (*12*) found this assumption to be true for highly heritable characters in tobacco. It may be invalid for correlations between characters with low heritabilities.

The partial correlations of weight in selected generations illustrate the trends in mass-selected and inbred derivatives of a character that exhibited good correlation with generations (r=0.78) (table 1) and high total correlations with other characters in M1. Shifts in partial correlations of weight with other characters in M1, M4, M7, and M9 were small and erratic (table 5). There were improvements in only five of the nine partial correlations, and only that with net thread cover differed significantly from the M1 partial correlation. Similarly, most of the partial correlations of fruit diameter were essentially unchanged in the four mass-selected populations; only that between diameter and net thread size was significantly improved.

The partial correlations of weight in inbreds were more variable than those in the mass populations (table 5); they often ranged above and below the partial correlation in the parent mass-selected population. Such partial correlations might be useful in the selection of parents in controlled breeding work after several generations of mass selection.

Very high correlation with generations (r=0.98) (table 1) suggested high heritability of blossom scar size; but its total correlation with other characters was very low in M1. The partial correlations in the mass-selected generations indicated little improvement. Most of the correlations in inbreds derived from M4 and M7 were low and ranged above and below those of the parent mass populations.

High heritability of net thread size was suggested by its high correlation with generations (r=0.86) (table 1). It showed small but often significant correlations, both favorable and unfavorable, with other characters in M1. Curiously, the low positive total correlation of net thread size with fruit weight was altered by removing effects of variation in other characters, so that the residual partial correlation in all populations was negative (table 5). The generally low values of all net thread size correlations except that with net thread cover (table 4) indicated that obstacles to breeding progress should be minimal.

The uniformly high positive correlation between net thread size and net thread cover in all populations suggested close linkage or pleiotropy of some genes controlling the two characters. Pleiotropy or close linkages of genes controlling other character pairs was suggested by uniform correlation in all populations of weight with diameter ($r_{12 \cdot 3 \cdots 10}$ in M1=0.854), weight with cavity size (0.204), diameter and cavity size (−0.411), sutureless and net thread cover (0.301), and, perhaps, soluble solids and cavity dryness (0.193) (table 4). It is reasonable to believe that pleiotropy occurs in all those character pairs. There were no uniformly high partial correlations in other character pairings. Thus, blossom scar size and stem scar size showed little indication of pleiotropy or close linkage with any other characters.

Soluble solids showed little correlation with other characters in M1 and responded little or not at all to index selection in this experiment. The partial correlations of soluble solids with other characters in successive mass-selected generations showed little indication of improvement. Such results agree with the lack of response of soluble solids to index selection.

In summary, the partial correlations indicated little increase in relations between most fruit character pairs under mass selection. The few exceptions could result from random variation; i.e., a small number of improved correlations would be expected by chance among the number of character pairs used in this study. Identical high partial correlations in all populations of certain character pairs suggested pleiotropy or very close linkage of genes controlling those characters. Biological considerations indicate plausibility of pleiotropy as the more likely explanation.

The greater ranges of the partial correlation coefficients in inbreds indicated high potential variation available for selection. The sporadic occurrence of improved positive correlations in inbreds suggested the presence of individuals with improved linkage relations for most character pairs in the later mass-selected generations. Appropriate testing, selection, and breeding procedures should accelerate the accumulation of favorable linkages in the later generations. The rare occurrence of several favorable linkages in the same inbred population suggest that the desired result may not be attainable by selfing individuals in M4 or M7. However, a very few random individuals were tested in selfed progenies. A larger number of selfed progenies from selected individuals in late generation mass-selected populations would undoubtedly yield far better progenies than those reported. Additional information will be required to determine whether continued improvement can be achieved more efficiently by continued mass selection, by fruit to row testing and selection, by selfing, or by some form of controlled sib-crossing.

SUMMARY AND CONCLUSIONS

Simple, phenotypic correlations among generation means for index-component characters in mass-selected populations of muskmelon C434–C–3 usually were similar to their correlations with generation number. The similarity suggested that improved relations among the characters paralleled their individual improvement from generation to generation. The correlation between means of different characters supported the data on improvement of means. Such support was helpful in indicating real improvement of characters that had only marginal levels of mean improvement.

The within-population correlations between characters and their changes with selection are of interest because such correlations, in the end products of selection, are those that will prevail in the resulting commercial product. Knowledge of high negative (unfavorable) phenotypic correlations is especially valuable because such correlations, if genetic in origin, hinder breeding progress by linkage. If environmental in origin, they hinder progress by blurring genetic segregations; and they persist in end products to prevent the production of fruits excellent in all characters. Thus, the breeder seeks to improve high negative, within-population, phenotypic correlations whether they are induced by either genetic or environmental factors. In other words, the breeder hopefully seeks to select those genetic factors that are stable and induce the same phenotype in a wide range of environments. This provides the argument for selecting in a wide range of environments in preference to selecting in a single environment or in closely similar ones.

High, simple phenotypic correlations between a few characters within base population C434–C–3–M1 and in all of its derived populations were interpreted to indicate that either pleiotropy or close linkage of genetic factors or prepotency of environmental factors controlled those relations. Character groups exhibiting high correlations included: (1) the fruit mass characters—weight, size, and diameter; and (2) the fruit appearance characters—appearance, net thread cover, net thread size, and sutureless.

The foregoing high correlations were exceptional. Low coefficients for within-generation, plant-to-plant, simple phenotypic correlation prevailed among most character associations. The relations were clarified and emphasized in partial correlations. Most of the partial correlation coefficients were nonsignificant. Furthermore, very few of them exhibited significant change after mass selection.

The failure to find a general trend of improved partial correlations seems at variance with the data on improvement of means for the individual characters. It suggests that improvement in character A was not associated with improvement in character B. If that is true, the linkages between genes for characters A and B have not been changed appreciably by eight generations of mass selection, and any breeding progress is a result of increased frequency of nonlinked alleles. It seems probable, then, that the plant material in C434–C–3–M9 is still at the bottom of the overall improvement curve and that several additional generations of selection would be required to yield the vast number of linkage changes required to produce improved partial correlations between all characters. Further, the progress toward homozygosis, resulting from a high percentage of selfing, may prevent adequate improvement in all characters by mass selection in naturally pollinated populations.

The low simple and partial correlation coefficients for most character pairs indicated that close linkages must have been lacking, balanced favorable against unfavorable, or negated by opposing environmental correlations. Data yield little support for one alternative over the others. Matzinger and Mann (*11*) and Matzinger, Mann, and Cockerham (*12*) demonstrated that negative genetic correlation and positive environmental correlation could interact to produce little or no phenotypic correlation between highly heritable characters in tobacco. Similar information would clarify the relations among muskmelon fruit characters reported herein.

Lacking such information, the generally low phenotypic correlations among fruit characters in muskmelon mass-selected populations were encouraging. There was little indication in the phenotypic correlations, with the possible exceptions of (1) soluble solids and cavity dryness, which failed to respond to index selection and (2) certain persistent unfavorable correlations between "positive" and "negative" characters, that strong, unfavorable genetic linkages would hinder progress.

Finally, it should be clear that zero phenotypic correlations would be satisfactory in the ultimate derived population, as long as each character varied within the acceptable range of character expression. The desired freedom from undesirable genetic correlations would be achieved sooner in mass-selected populations than in controlled-mating populations after the cessation of selection. The mass-selected populations would have attained a high level of equilibrium under natural reproduction for all loci unaffected by selection. In contrast, populations selected with artificial mating designs would have achieved equilibrium for the imposed mating design at many loci. They would be in disequilibrium for the natural mating design, which includes part self- and part cross-pollination. They would then seek new equilibrium levels of genotypes at many loci after the cessation of artificial mating and the initiation of natural mating for seed increase.

Freedom from undesirable environmental correlations would appear more likely to result from cyclical selection in a range of environments than from continuous selection in a single environment. Thus, current information supports the use of mass selection in a cyclic sequence of different environments for breeding programs designed to obtain varieties with wide ranges of adaptation.

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